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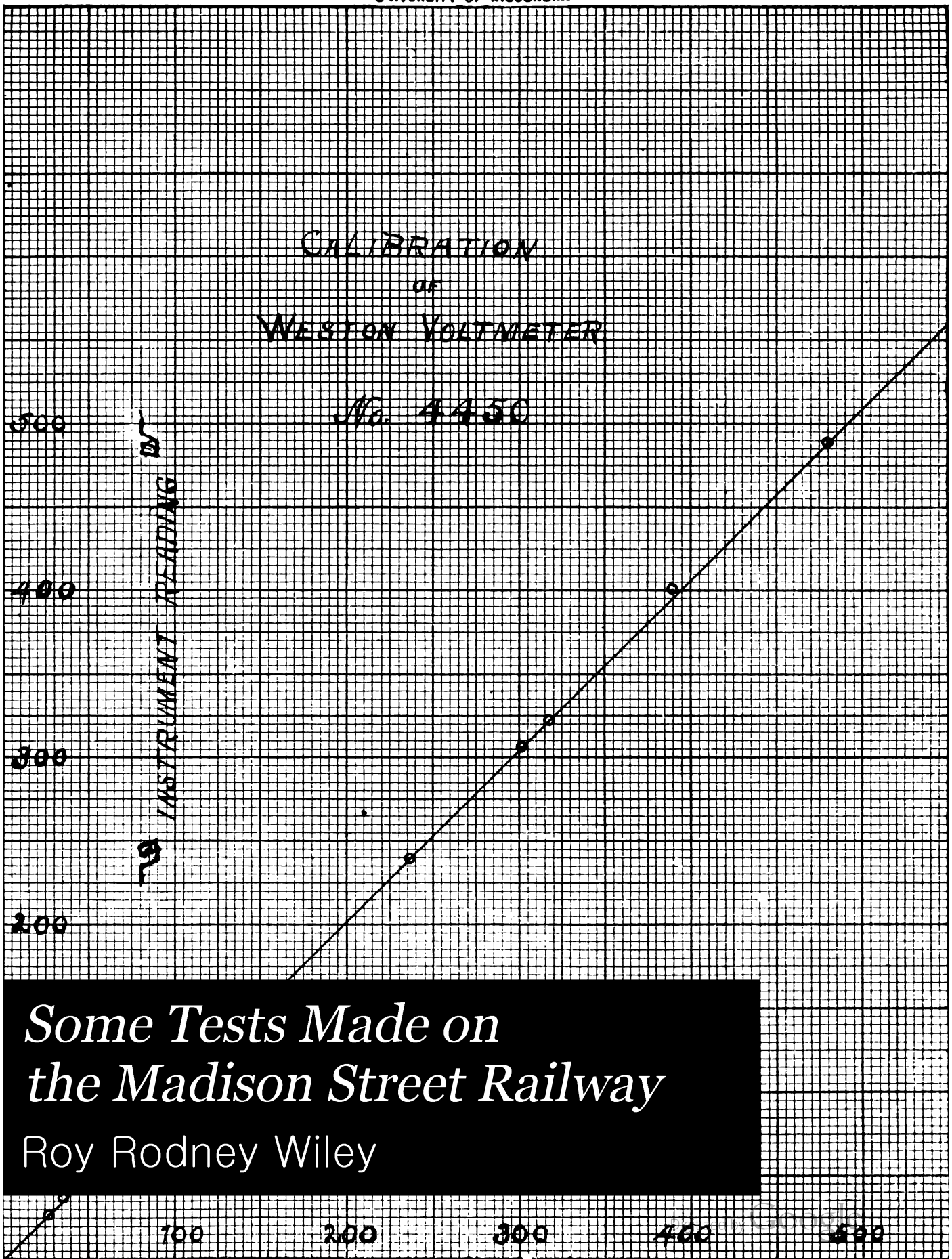

Some Tests Made on the Madison Street Railway

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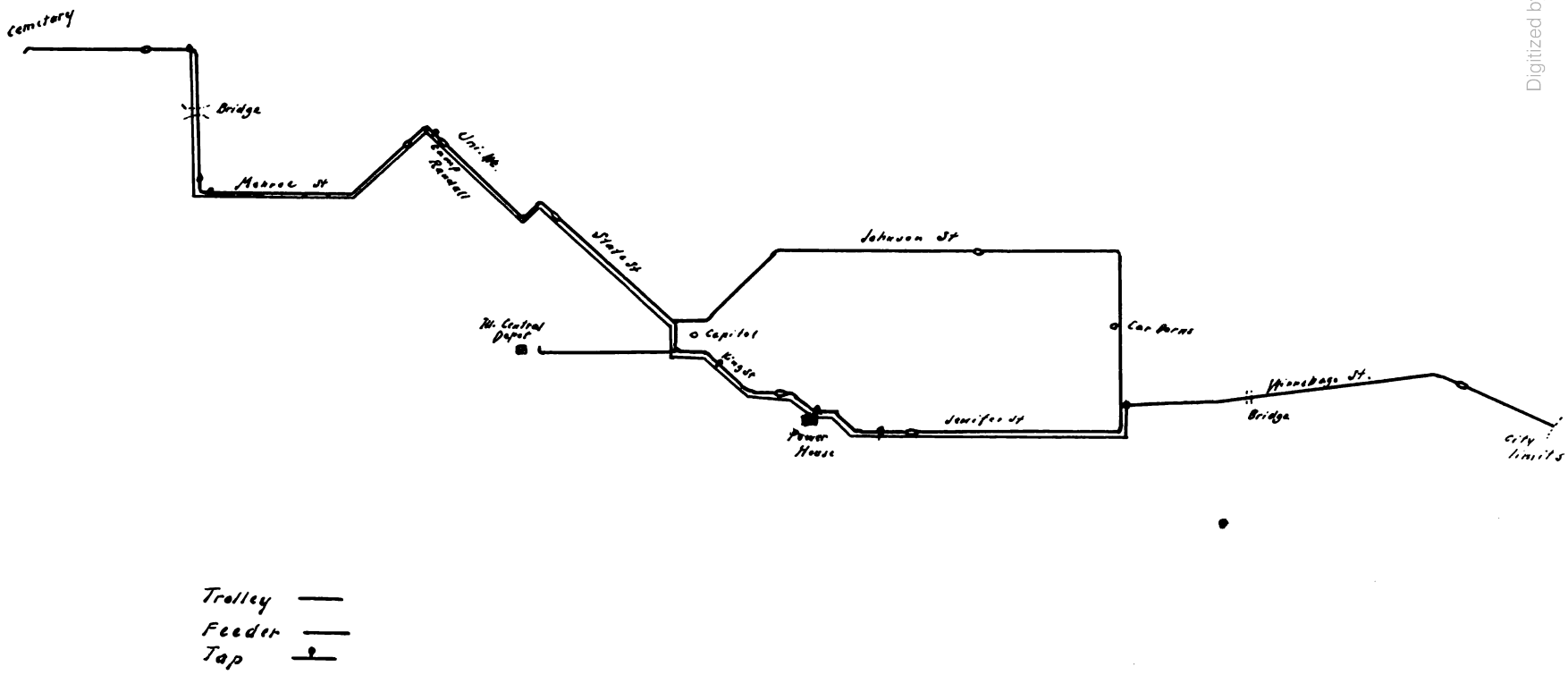

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These tests of the Madison St. Railway line were made to determine the amount and fluctuation of the power required, as affected by the varying conditions of the grades, motormen, track, equipments, loads carried, etc. and to determine other incidental data of interest and importance. The tests were all made on the regular service runs, no alterations being made in favor of the tests. A complete description of the line, cars, road-bed and power-house is given, enabling the tests to be compared with those made on other roads under similar conditions.

Mr. Hermann S. Hering gives the following general conditions which affect the performance of electric cars:-

a. Character of the electrical equipment of the car, including motors, controllers, trolley wire connections, etc.

b. Mechanical equipment, including trucks, wheels, etc.

c. Character and condition of tracks and road-bed, affecting the traction coefficient and speed limit.

d. Curvature.

e. Grades.

f. Line resistance; including feeders and return circuit.

g. Potential difference of the line; including the drop and the variation due to other cars.

h. Load; number of passengers, trailers, etc.

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j. Number of stops.

k. Schedule run; whether express, accommodation etc.

l. Wind resistance.

m. Controller position; motors in series or parallel or with resistance.

n. Character of the operation by the motorman. The quantities involved in the performance of the cars, and affected by these conditions, are:

p. Potential difference applied.

q. Current used by the motors; including the division between the motors; consequently the

r. Electrical horse-power applied to the motors.

s. Watt-hours required for any portion of the road or the total.

t. Watt-hours per car mile.

u. Losses.

v. Speed.

w. Traction coefficient.

x. Net efficiency.

These conditions have been considered in this thesis with the exception of m, l and x.

The results of two typical tests and the average power used on the important curves and grades are presented in tab-

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(See pages 20a... and 27a...)

ular form. The results obtained on outgoing and return trips are plotted on separate sheets for all the trips. On another sheet the average results of all the trips are plotted.

General Description.

From the diagram, page 1, may be seen the extent of the company's lines and feeding system (also see map page 41). The main line starts at Elmside, beyond the city limits, on the northeast. From here it extends through a residence portion, the main part of the city, and another residence portion to Camp Randall. After Camp Randall, it extends through a thinly settled portion over several severe grades. Near the terminus is a viaduct over the Illinois Central Railway track. The western terminus is at the Forest Hill Cemetery. The total length of the main line is 32,346 ft. or 6.1 miles. There are few level stretches along the length of the line; a great number of gentle grades, and a few severe grades.

The Johnson St. branch may be said to begin at the car barns on Baldwin Street, as the cars start at that point. The road turns, at Baldwin, and extends a considerable distance on Johnson street. This portion is quite level and is through a residence district. From Johnson street, the line

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extends up Hamilton over a four per cent grade to Capitol Square. It circles half of the square and turns down W.Main street over a four per cent grade to the Illinois Central depot. The total length of this branch is 13,608 ft.or 2.58 miles.

Some of the important distances along the system are as follows:-

Length of main line	32,346 ft.
Length of branch line	13,608
Length of feeder from power house east	4,400
Length of feeder from power house west	17,400
Length from Williamson and Baldwin to Carroll and Mifflin	9,800
Length from Baldwin St. to Elmside	7,219
Length main line from Williamson and Baldwin to Carroll and Mifflin	8,630

Operation of the Road.

It is customary to run 6 and 7 cars on the main line and 3 cars on the Johnson St.branch. No special arrangement is made for an exact time schedule and the cars are given fifteen minutes headway. The company does not generate its own power but rents the power by contract from the Madison Gas and Electric Co. Extra cars and trailers are run on special occasions. Extreme loads frequently occur at Camp Randall and

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at Schuetzen Park, where picnics and games draw large crowds. The road has heavy traffic also on Sundays when many go out to the cemetery.

Equipments.

a. Power House.

The power house, the location of which is shown in the diagram page 1 , is well situated as regards a minimum of copper required for a given average drop, in the feeding system. The theoretical centre of electrical distribution of the system has been found to be a point near Hamilton St. or about half a mile north-west of the station. The station's proximity to Lake Monona and the steam railroad, allows economy in the coal handling and in water for the condensers, and the station is better situated than is the average of most city roads.

The station is well equiped with generating machinery and careful tests have shown that it is being run economically. (See vol.XVI, Trans. Am. Soc. M. E. Test of a combined power and lighting plant.)

The boiler room is equipped with two Hazelton return tubular boilers, rated at 110 H.P. each and a Stirling boiler of 200 H.P. capacity.

In the engine room are three Russell compound, condens-

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ing engines. One of them is belted to two, 90 K.W., 500 volt, Ry. generators. These generators are used continuously through the day's run which lasts from about six A.M. to midnight or 18 hours. At times of heavy traffic, the generators are too heavily loaded, and the station should have more generators for the railway circuit so as to relieve the operating dynamos when overloaded. It is also customary to have a reserve generator for emergencies.

For the railway circuit there is a separate switch-board fully equipped with circuit-breakers, ammeters, voltmeter, watt-meters and rheostats.

b. Equipment of road-bed.

The line is single-track throughout, with the exception of a short stretch around the Capitol Square. The curves, at the street corners, have radii varying from 35 to 80 ft. (See page 27). The road is well ballasted and the ties are of cedar 6 x 8"; 7 ft. long, and placed 18" from center to center. The rails, with the exception of those on the Elmside extension, are 60 lb., T rails. Those on the Elmside extension are 30 lb., T rails. The joints are of the supported type, there being a tie under each joint. All joints, except in the portion between Camp Randall and the cemetery, are bonded with 24 inches of #0.B. and S soft copper wire.

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The bond is known as the channel pin bond, holes being drilled in the web of the rail at the ends of the fish-plates. From Julia St. to the cemetery, a bond known as the "Horse-shoe bond" has lately been installed. Several of these bonds have given trouble by burning out.

During our tests a new turnout was being put in near Camp Randall; several joints at this point had not been bonded, and this probably caused the excessive voltage drop noticed beyond this point.

On the main line the road is fairly smooth and allows a high speed to be maintained, but on Johnson St. the road-bed is so poor that the cars violently see-saw with but an average speed.

c. Equipment of Feeding System.

The line has the ordinary span-wire construction, with the exception of a short stretch around the Capitol Square, where ornamental, iron, centre-poles are used. The poles are 30 ft. cedar poles, spaced at an average distance of 100 ft. The span wires are of No.5, galvanized iron with insulated connections to eye-bolts at the poles. The trolley wire is of No.0, B and S copper and has a clearance of 18 ft. from the ground. At rail-road crossings several trolley-wire hang-

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ers are branched to ensure against the wire coming down at these points. The feeder wire is of No. 0, B and S, insulated copper and is carried on the poles, parallel to the track. The total length of the feeder wire is 21,800 ft.

The feeding system is known as the "ladder system" and a sketch of the arrangement will be found on page 1 . Beginning at the east end, the first tap is at Williamson and Baldwin Streets, and a little nearer town is one at Patterson and Jenifer Streets. Then there is one at the power house; the turnout on King Street, Camp Randall, Wingra Park, and the last one is on Regent Street.

Some of the points of feeding are unnecessarily close and the feeding system might be materially improved. The type of feeding system is satisfactory for conditions, as they exist in Madison, but a city having denser traffic would require the feeding system to be blocked off in independent sections so as to make provision for fires or other emergencies.

a. Car Equipment.

The bodies of the open cars were made by the Wells, French and Co. of Chicago. and the bodies of the closed cars were made by the St. Louis Car Co. The trucks, with the ex-

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ception of those on three open cars, are the Mc.Guire trucks. All the other cars are equipped with the Curtiss trucks. The wheel bases are; - closed cars 6.6 ft.; Curtiss trucks 7 ft.; and for the other open cars, 7.6 ft. The closed cars are equipped with two "W.P.30", single reduction, 15 H.P. motors and the open cars, with two, "G.E.800" motors, rated at 25 H.P. each. This last named motor is a recent type and gives good satisfactiom. Some of the old cars still have cast iron gears but most are equipped with cut steel gears. All of the motors are connected to the trucks by the "nose suspension".

The trucks of the closed cars weigh 3200 lbs. Wt. of W.P. motor is given below in detail:-

Wt. of motor without gear or gear cover	1735#
Wt. of axle gear	202
Wt. of upper field casting	385
Wt. of malleable iron cover	145
Wt. lower field casting	420
Wt. of frame complete	895
Wt. of field spool	168
Wt. of armature and pinion	650
	4600#

The closed cars weigh 14700# complete and the open cars weigh 17000#. A print of each type is shown on the last

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pages. The closed cars were installed in 1882 and the open cars within a few years of the present time (1898). The controllers in use are the G.E., K.2. controllers. G.E. rheostats, canopy switches, lightning arresters etc. complete the electrical equipment. The cars are heated by coal. The best criterion of the car equipment is the repair account of the railway company. The repair account of the line under consideration is small, only one man being employed to do repair work on the cars.

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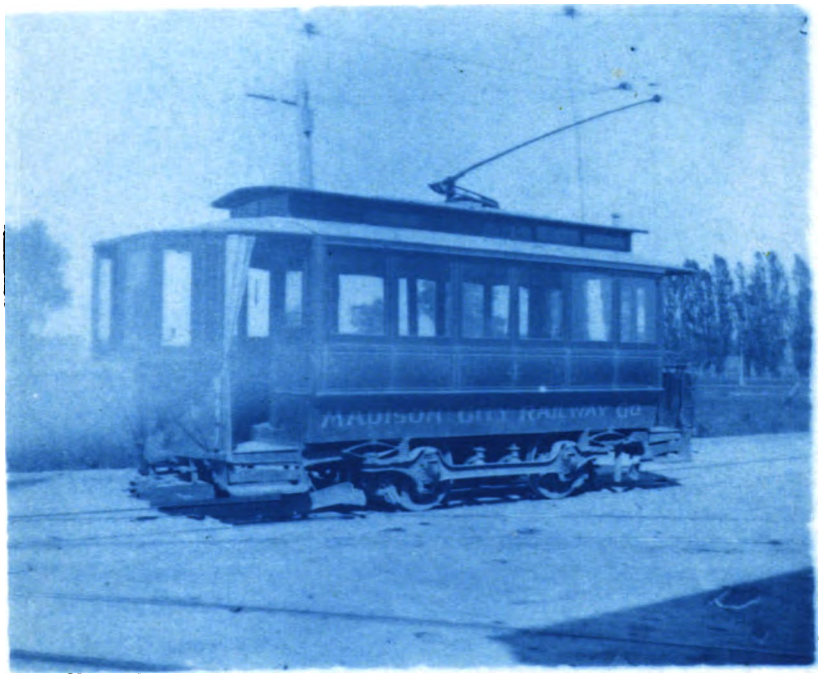

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Methods of Testing and Instruments.

All of the electrical instruments used in the tests were from the laboratory of the University of Wisconsin. They consisted of two Weston Ammeters, one Weston volt-meter and a Thomson-Houston, recording watt-meter of special make for railway work.

In order to make some determinations on the pull exerted by the motor cars, a rather rough dynamometer was constructed (See page 12 and drawing). This consisted of a heavy 9/16 inch spring, so arranged as to be put in compression when a pull was exerted at the eye-bars. This deflection would be small, even under the worst conditions, and in order to make the deflection readable, a steel rod was pivoted near the spring so that the upper point of it described an arc of a large radius. The lower part of this rod was connected by a steel wire to the opposite end of the dynamometer. A graduated frame, hinged at the top of the car was so disposed that the deflection of the steel rod could be noted.

The device worked fairly well but could not be relied upon to give more than a rough degree of accuracy. We calibrated the dynamometer with an Olsen testing machine (See calibration curves.) As we had no automatic speed recorder,

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the following method was devised.

A telephone receiver, battery and a spring contact were connected in series and so arranged that each revolution of the car axle closed the circuit and caused a click in the telephone receiver. By means of a stop watch the time between 11 clicks or during 10 revolutions, was accurately noted. From the records of the trips, knowing the diameter of the wheels, all of the speeds have been computed in miles per hour. While this method was not as convenient as a method giving the instaneous speed, yet it was thoroughly satisfactory for the tests.

The electrical instruments were carefully calibrated with a Kelvin balance and the watt-meter was calibrated by correcting the constant at different loads. (See calibration curves)

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Resistance of Feeding System and Ground Return.

A car was run to the end of the line and the brake was firmly set. Care was taken that this car was the only one using current on the system. Upon turning the controller to the first position, readings were taken of the current and voltage. At the same time an assistant took readings of the station volt-meter.

Let V = voltage at station

V' = voltage on car

C = current.

The resistance between the station and the point of measurement is

$$R = \frac{V - V'}{C}$$

We made these tests at both ends of the line and from the results shown on the next page, the resistance of the whole system has been computed.

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Date	Point of Test	C	V	V′	Av. R
May 22	Wingra Park	37	495	440	
"	"	30	465	550	1.206 ohms
"	"	31	470 V′	500 V	
May 26	Elmside	34	404	485	
"	"	25.5	412	485	
"	"	22	424	485	2.539 ohms
"	"	21	440	485	

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Analysis of Resistance of Separate parts of System.

Resistance of main line overhead, trolley and feeder, between (Williamson and Baldwin) and (Carroll and Mifflin Streets) .3378 ohms

Resistance of overhead circuit of Johnson St. branch to Carroll and Mifflin 1.009

(Note - The two sections above constitute what is termed the loop. See diagram page 7)

Resistance of two in parallel .252

Resistance of overhead circuit of Elmside extension (from Baldwin to Elmside) .743

All of these values just determined, together with the resistance of the ground return, gave us our second reading of 2.539 ohms

Resistance of return = 2.539 - (.252 + .743)= 1.544 ohms

Total resistance of overhead circuit .995

Resistance of overhead circuit equals 64 per cent of return.

Assume resistance of return in loop=$\frac{.252}{.64}$ =.39 ohms.

Total resistance of loop = .64 ohms

Grand total resistance of system = (2.539-.64)+1.206=3.105 ohms

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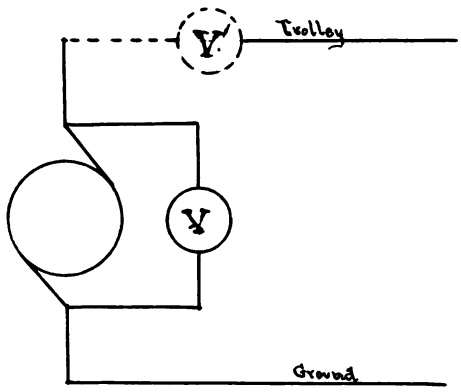
Insulation Resistance.



The diagram indicates the method we employed for measuring the insulation resistance of the line. The instrument used was a Weston volt meter. The first connection was made across the dynamo terminals, as shown by the full lines, and the voltage V was read. The next connection was made by putting the volt meter in series with the trolley wire and another voltage V′ was read. Now if r be the resistance of the volt-meter, the insulation resistance is

$$R = \frac{r(V-V')}{V'}$$

The following readings were taken from which the resistance has been calculated.

r = 68,784 ohms

V	V′	R
517	512	671.71
515	510	674.35

Av. R = 673.03 ohms

This is extremely low, for insulation resistance, making the resistance per mile only about 8.68 x 673.03 = 5841.64 ohms.

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The diagram, on the following page, shows the connections of the instruments on the car.

Between the canopy switch and controller, an ammeter and recording watt meter was placed. This ammeter recorded total amperes. Another ammeter, in series with one of the motors, showed the division of current between the motors. There was an observer at each instrument to take the readings at a given signal. One observer sat near the motorman and noted the time that the current was on and off and the duration and number of stops, and another observer gave the signals and kept the readings checked. The poles had previously been numbered from end to end of the line, and signals were usually given as we passed a pole so that the readings could be checked by making a note of the pole number.

Eleven single trips were made, two on the Johnson St. branch being in the nature of preliminary runs. Eight regular single trips were made on the main line and one single trip was made with the dynamometer car.

Application Results.

The grades of the main line were obtained throughout and from these, the profile of the road has been plotted. With the poles for reference points, the volts, amperes, E.H.P.

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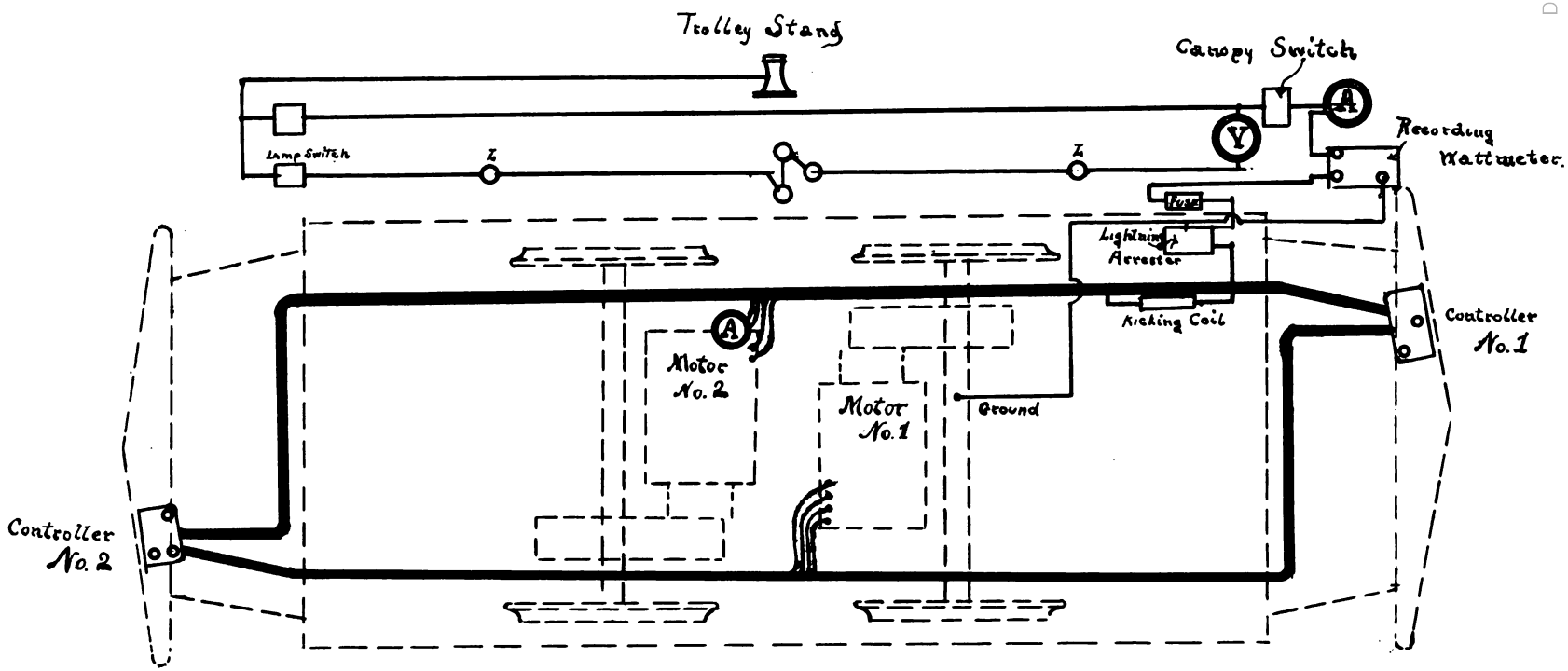

Connections of Instruments

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and speed have been plotted for each trip. The dynamometer pull has been plotted, in addition, for one of the trips. On page 27ω, a grand summary of all the trips is given, also a summary of the power used on the principal grades, and a summary of the power used on curves. The power has been determined by taking an average of a large number of readings, care being taken that the conditions were the same as far as type of car and points of reading were concerned.

The starting currents are of some interest and these will be found tabulated. See page 27d.

Determination of traction coefficient.

When a car is pulled along a level track the force exerted at the draw bar is called the tractive force. It is the force that must be applied to overcome the friction of the journals, rails, and in the case of the motor car, the friction of gear wheels, brushes and armature. Although the friction of the motor parts and gear does not vary with the weight carried, yet it is customary to express the coefficient in pounds (horizontal) per ton of weight carried. In going up a grade the force exerted is composed of two components, a lifting component and a traction component.

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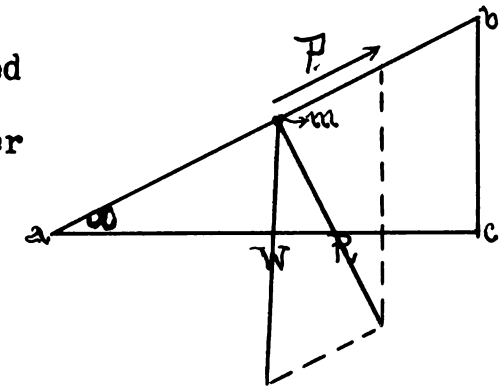

Suppose the weight M is being pulled up the grade a,b. The grade in per cent is expressed by $\frac{bc}{ac}$. Let W = weight of M, R the pressure normal to the surface, and P the draw bar pull or force which is equal to the sum of F and L, or the component required to raise the body. Then we have:-

$$F = \mu\ (R)\ \sin \mu = \frac{F}{R}$$

$$L = W \sin \alpha$$

$$R = W \cos \alpha$$

$$F = \mu\ W \cos \alpha$$

The total pull as measured by the dynamometer then equals:-

$P = L + F = W \sin \alpha + \mu\ W \cos \alpha$ The coefficient

$$\mu = \frac{P}{W \cos \alpha} - \tan \alpha$$

The value of angle α is small in grades on electric roads and the value of cos α will practically be 1 for most values. We may say then that within one per cent

$$\mu = \frac{P}{W} - \tan \alpha$$

But tan α = per cent grade. Therefore traction coef. = $\frac{\text{dynamometer pull}}{\text{weight of car}}$ − per cent grade.

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Mechanical Horse Power

The components of the mechanical H.P. are as follows:-

1. Lifting.
2. Horizontal traction.
3. Acceleration.

Let W = weight of car

S = speed in ft.per second

t = time in seconds

then the

Lifting H.P. $= \frac{W \times S \times \% \text{ grade}}{550}$

Traction H.P. $= \frac{W \times S \times \text{tract.coef.}}{550}$

Accelerating H.P. $= \frac{W}{550g} \frac{S - S}{t} S$

where S and S are the speedsat beginning and end oft seconds.

The traction coefficient, as determined from the results on trip 5 a, are given where it appeared that the car was running at uniform speed. (See page 31)

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Trip No.1 a & 1 b, May 14, Started at 9 A.M. Open Car No.23.

Elmside to Camp Randall
Camp Randall to Elmside.

- - -o-- -

Pole	Volts	Amp. total	Amp. 1st. Motor	Amp. 2nd Motor	Speed per hr.	E.H.P.	Observation No.
25	520	11	11		11.8	7.7	2
27	528	35	17.8	17.2	11.8	36.5	3
31	480	17	17.	17	8.4	11.	4
34	360	20	20.5	20	6.8	9.7	5
37	468	17	16.6	17	9.8	10.6	6
40	460	49	25.	24	16.2	30.3	7
43	456	36	17.	19	13.2	22	8
46-47	484	14	12	14	9.3	91	9
48	490	45	19.6	25.4	13.8	21.6	10
52	488	47	23.2	21.8	13.8		
60	500	11	11.	11	9.8	7.7	3
63-64	520	25	22.2	25	6.8	17.5	4
67	520	23	24.5	23	8.1	16	5
69	516	42	22	22	11.4	28.	6
71	512	36	17.8	18.2	14.9	24.6	7
75	516	34	16.1	17.9	13.1	23.5	8
77	520	34	9.6	13.8	13.8	23.8	9
79	508	39	24.5	12.7	12.7	26.6	20
80-81	500	26		26		17.4	1
81	520	36	16.1	16	10.1	25.2	2
89	528	10.5	10.5	10.5	9.8	11	3
93	532	0			8.3	7.4	4
94	520	16	16.			11.2	6
94	528	14.5	14	14.5	13.8	10.3	7
103-4	532	18.5	17.8		9.8	13.1	8
106	532	19.5	20	19.5		13.9	9
107	528	30				21.1	30
108	528	23.5	23.2	23.2	13.8	16.3	1
109	516	59	29.5	29.5		40.6	2
110-1	508	55	27.2	27.8		37.5	3
112-3	524	40	32.5		11	28.2	34
116	492	62	28	34		41	6
123	528	26	24.5		9.25	81.1	7
127	504	17	25.4			11.5	40
130	508	18	17.8		9.25	12.4	1
132	516	32	38			22.2	2

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Pole	Volts	Amp. total	Amp. 1st. Motor	Amp. 2nd. Motor	Speed per hr.	E.H.P.	Observation No.
151	520	12	11.3		12.7	8.7	3
155	524	12.5	11.8	12.5	11.4	8.8	4
162	508	9	8	9	13.8	6.1	6
164	480	31	16	15	17	20	7
166	484	30	13	17	13.8	19.6	8
168	512	16	16.1	16	8.5	11	9
171	508	18	16.6	18	9.8	12.3	50
173	488	21.5	20.5	21.5	8.5	14.1	1
174	460	30	21.1			18.7	2
175-6	456	32	29		7.6	19.7	3
178	416	37	17.8	19.2	13.2	20.6	4
180-1	480	19	17.2		11.4	12.3	5
183	460	56	29.2	27	11.4	34.5	6
185	464	44.5	22.2	22.3	11	27.6	7
187	464	45.5	22.2	22.3	11.4	28.3	8
192	460	40.5	20.5	20		25	9
199	490	23	20.5			15.2	60
200	500	19	17.8			12.8	61
202	500	23	20.5		7.6	15.5	2
203	500	17	16.1	17	8.5	11.5	3
207	472	17	17.8	17	6.8	10.7	4
202-3	460	24	24.5			14.8	5
200	444	16	15.5		8.4	9.3	6
199-8	480	16	16.		6.5	10.3	7
197	520	15	14.7		9.8	10.4	8
195-6	416	56	32.5	23.5	9.8	31.2	9
194	452	46	23.8	22.2	13.1	27	70
180-1	520	21	20.5		6.5	14.7	1
178	480	18	24.5		10.9	11.6	2
172	480	22	16.6		8.9	14.2	3
169	476	13	12	12	8.6	8.3	4
166	440	21	21.1	21.1	7	12.4	5
163	436	39	20.5	18.5	10.9	22.3	6
160	460	43	22.2	20.8	14	26.6	7
157	500	13	12		9.8	8.7	8
155	530	16	15.5		9.5	11.4	9
153-2	504	46	24.5	21.5	11.8	31.3	80
149	516	14.5	14.7		9.2	10.1	1
146	490	62	32	30	11.8	40.8	2
145	488	54	26.5	27.5	14.8	35.4	3
141	500	46	23.8	22.2	11.8	30.8	4
140	508	50	50		5.3	34.0	5
139	512	46	37	39		31.6	6

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Pole	Volts	Amp. total	Amp. 1st. Motor	Amp. 2nd. Motor	Speed per hr.	E.H.P.	Observation No.
138	496	70	32	38	53	46.6	7
137	488	72	37	35	9.2	47.2	8
136	488	73	35	38	9.8	47.8	9
135	480	66	32.5	33.5		42.6	90
134	492	64	32.5	31.5	9.8	12.2	1
133	484	63	32	31		41	2
132	520	22	28.1			15.3	3
132-1	508	33	29			22.5	4
130	520	24			8.4	16.8	5
123	508	44	24.5		7.4	30.6	6
122	540	0	0			0.	7
108	440	30	29		7.4	17.8	8
106	536	25	24.5			18.7	9
104-3	528	18	25.4		8.2	12.7	100
102	524	65	29.7	35.3	1.4	45.6	1
100-99	536	18	22		9.8	13.	2
96	540	0	0		6.5	0	3
95	480	60	32	28	9.8	38.5	4
94	440	25	25.4	25	7.8	14.8	5
93	520	26	24.5		7.4	18.2	6
90	516	45	23.2	21.8	12.2	31.2	7
87	520	57	29.7	27.3	16.2	39.6	8
85	520	48	24.5	23.5	17.1	33.5	9
82	508	46	23.5	22.5	16.2	31.5	110
76	520	33	12		16.2	9.1	1
72	520	35	17.2	17.8	18.4	24.5	2
70	500	50	20.5	19.5	11.4	33.5	3
65	520	24	21.1			16.8	4
64-3	416	40	34.3		7	22.4	5
61	496	49	24.5	24.5	14.7	32.6	6
59	520	45	14		14	31.4	7
45	480	26	25.4		7.4	16.7	8
41	440	44	21.1	22.9	11.3	26.1	9
38	468	41	21.1	19.9	14.7	25.7	120
34	500	21	17.5		4.7	14.2	1
30	440	44	19.6	24.4	11.8	26.0	2
27	432	34	17.2	16.8	16.4	19.7	3
25	464	35	17.8	17.2	17.4	21.8	4

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Trip No.5. May 22.(#23 and trailer.)

Car Barns to Cemetery.

Obser.	Pole	Volts	Amp.	Speed	E.H.P.	Draw bar Pull	% Grade
1	68	520	26	8.7	18.1	390	2.0
2	70	536	21	9.8	15.1	225	0.7
3	71	532	17	11.2	12.2	265	0.6
4	72	500	14	11.8	9.7	210	0.0
5	73	495	23	6.6	15.3	150	0.1
6	74	490	30	9.1	19.7	210	1.4
7	76	504	35	8.4	23.6	210	2.3
8	78	526	66	9.1	46.5	420	2.3
9	80-81	524	34	5.9	24.0	310	0.0
10	81	520	41	5.9	28.6	480	0.0
11	83	516	58	11.8	40.0	265	1.2
12	84	520	49	14.8	34.2	210	1.3
13	92	520	25	9.5	17.5	150	1.3
14	93	552	0	7.4	0.0		1.3
15	93.4	550	25	4.9	18.4	265	1.3
16	95	528	26	11.8	18.3	210	1.2
17	100	544	51	9.8	37.2	265	.4
18	104	540	21		15.2	105	.4
19	107	540	25	4.9	18.0	310	1.0
20	108	540	29	4.9	22.5		3.3
21	109-10	520	85	11.8	59.2	310	3.3
22	111-12	512	76	12.4	52.2	310	3.4
23	112-13	540	0	8.4	00.0		4.1
24	113	520	59	9.8	41.2	425	4.0
25	113-14	480	150	9.8	96.5	850	4.8
26	115	492	98	11.8	65.0	480	4.8
27	116	500	96	11.2	64.1	480	4.7
28	117-18	512	94	11.8	64.5	310	4.7
29	120	532	93	9.1	66.5		3.8
30	122	480	40	5.4	31.0		3.6
31	123	520	42	5.9	29.3	325	3.2
32	127	512	33	7.4	22.6		.7
33	132	508	38	8.4	25.7	210	.7
34	135	492	0	4.2	00.0	210	3.2
35	140	548	0	10.7.	00.0		
36	141	540	19	12.4	13.7		
37	144	520	0	12.4	00.0		
38	150	540	0	11.2	00.0		1.2

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Obser.	Pole	Volts	Amp.	Speed	E.H.P.	Draw bar Pull	% Grade
39	152	500	63	13.1	42.2		1.2
40	154	500	49	14.7	32.8		level
41	156	500	19	3.9	12.7		
42	164	508	17	12.4	11.6		
43	166	556	00	14.7	00.0		
44	172-3	520	25	5.9	17.5	800	.4
45	173	520	26	7.4	18.1	150	3.0
46	174	496	41	5.9	27.2	310	3.0
47	175	496	43	4.2	28.8	480	.2
48	178	480	50	12.4	32.1	210	.2
49	180-1	508	34	4.9	23.2	310	
50	181	472	37	6.9	23.5	310	2
51	183	476	80	11.8	51.1	425	2
52	186	456	60	13.8	37.0	210	
53	188	432	58	12.4	33.0	250	
54	189	452	55	14.7	33.5	210	.3
55	197	524	17	11.8	12.1		
56	199-200	484	30	6.9	19.4	105	
57	200	492	38	5.9	24.6	370	
58	205	470	25	9.8	15.8	105	
59	208	472	00		00.0		
60	210	448	36	3.7	21.5	425	1.7
61	210-11	460	56	3.7	34.5	640	
62	211	416	55	4.5	30.8	690	5.5
63	212	380	120	6.9	61.2	850	5.5
64	213	360	98	8.4	47.3	480	4
65	214	380	75	9.8	38.2	310	
66	219	460	20	5.9	12.4	210	
67	220	528	00		00.0		
68	229	540	00	6.5	00.0		
69	229-30	416	45	4.9	25.2	320	2
70	231	340	93	8.4	42.5	480	3.8
71	232	360	75	8.4	36.3	210	3.8
72	233	400	79	9.4	42.5	210	3.8
73	235	300	60	7.8	24.0	105	2.6
74	237	320	65	8.7	28.1	150	2.4
75	239	384	79	9.0	40.6	265	4
76	246-7	440	25		14.9		
77	247	448	40		24.0	590	5
78	250	360	88	8.4	42.5	370	6
79	251	376	100	6.9	50.2	445	6.5
80	252	400	105	8.4	56.5	425	2
81	256	444	25	5.9	14.9	370	5

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Discussion.

Trip numbers with subscript (a) denote outgoing trips and with subscript (b), return trips.

Round trips 1 and 2, were made between Elmside and Camp Randall; round trips 3, 4, and single trip 5 were made between Elmside and the cemetery. Round trip 6 was made on the Johnson St. branch between the car barns and the Ill. Central depot.

Trip 1 a. (See curves. Summary) The start was made at an hour when there was little traffic. But eight stops were made and the stops, per car mile, were below the average. The watt-hours, per car mile, were the least of any of the trips. The average E.H.P. was also the least of any of the trips. A fair average speed was maintained, the maximum being again less than those of the other trips. Thus we see that the motorman was quite efficient, running the cars at a fair average speed but not racing. He kept the current on for a longer time than the average but was careful in its use. (Note: The load carried on first two round trips was about the same).

1 b. The return trip was made with the same motorman. More stops were made, the stops per mile being up to the

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average. The mean E.H.P. was higher than on the outgoing trip, while the speed and time of current consumption were about the same. The watt hours per car mile were greater on the return trip and as other conditions were similar, it appears that the increase of power may have been due to the increase in the number of stops. However, a large portion of the outgoing trip was down grade, which is the best explanation of the difference.

Trip 2a. (See Curves and Summary)

This trip was also made at a time of light traffic. As the conditions were similar to 1a, the two trips may be compared. The watt hours and speed were about the same. The time of current use was smaller in 2a than in 1 a and the average E.H.P. higher, showing that the motorman, on this trip, attained the same result by using power for a smaller time duration and working the motor a little harder.

Trip 3a. (See Curves and Summary)

This trip was made at a time of light traffic and the loads carried on 3a and 3b were about the same as the loads of the previous trips. This time the car was run to the terminus, over some bad grades, which had not been encountered before, and over a poorly bonded portion. An increase

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in the watt hours per car mile, for this trip and the other trips extending to the terminus, clearly shows the difference between the power required on the road, from Elmside to the cemetery terminus and from Camp Randall to Elmside. The average of the power required on the former was 37 per cent greater than the power required on the latter. The watt hours per car mile on this trip were the greatest of any of the trips. A fair average speed was maintained and the time of current consumption was also the greatest of any of the trips. The motorman was very poor, the power being used much longer than necessary, and an inspection of the curves for trip 3a will show that he kept current on, even when going down hill. In this connection, it is interesting to note that Mr. Hering has had some experiments carried out with a view to determine how much the motorman can save in power by being careful. A car was taken out on the Pikesville road near Baltimore and a run was made with an experienced electrician at the controller. The latter was given instructions to handle the car in the most careful manner, using a minimum of current and running as close to the schedule time as possible. The number of watt hours used on this trip was 73 per cent of all the trips going, and 68 per cent of all the trips returning. Compared with four trips of the regular service

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tests, in which the number of stops and passengers were about the same as in the special test, the proportion was 85 per cent going and 74 per cent returning, a saving of 15 and 26 per cent respectively or an average of 20 per cent.

For the sake of avoiding exaggeration and allowing that such expert motormen could not readily be obtained, he considers that it would be safe to halve this figure and take 10 per cent as the amount of energy that can readily be saved by more careful handling of the controller. He made several subsequent tests which corroborated his deductions.

We may now see of what magnitude this saving would be on the Madison Electric Railway.

From the summary, page 21a, we can see that the average watt hours, per car mile of all trips made on the total length of the main line, is 1583.9. The average watt hours then required for a round trip = 12.2 x 1583.9 = 19,323.6. A saving of 10 per cent is 1,932.4 watt hours.

The Madison Gas and Electric Co. generate their power for probably something more than 2 cents per K.W. hour, but to be on the safe side we will assume that the power costs them this much. Then we will have a saving of 3.96 cents per round trip. The cars on the main line make 10 trips a day and the saving per car per day will be 39.6 cents or $140.890

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per car, per year. The company runs 7 cars on this part of the road and the total saving for all the cars per year would be $986.230. (If the company generates its power, average practice indicates that the cost per K.W. hour would be $.00962)
(See St. Railway Journal 1897— I.D. Jandy)

Trip 3b. (See Curves and Summary)

This trip was run with the same motorman as before, (3a). The stops per car mile were less than on the outgoing trip, a higher maximum speed was attained, and the mean speed was higher. The mean and maximum E.H.P. and the load were about the same in the two cases. The watt hours were considerably less and the time of current consumption was much less. An inspection of the curves for this trip, will show that in several instances the motorman used power on the down grades.

Trip 4a. (See Curves and Summary)

This trip was made at a busy time of the day and differed from the other trips in having the heaviest passenger load. The stops per car mile were the most of any of the other trips and the average speed was the ~~least, of any of the trips~~, as we might expect, owing to the large number of stops. An inspection of the curves will show that the motorman was reasonably economical with the power. Although the passenger weight was much greater on this trip than on

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3a and the stops were also greater, the more careful motorman of trip 4a used 36 per cent less power than the motorman of trip 3a.

Trip 4b. (See Curves and Summary)

This being the return trip of the previous run, there was another heavy passenger load. The number of stops per car mile was slightly above the average and the mean speed was low. An inspection of the curves show that the motorman was careful in his use of the power. Though the number of stops and passengers were much greater than in the case of 3a, the more efficient motorman of trip 4b used 19 per cent less power.

Trip 5a. (See Curves and Summary and tabulated trip.)

This was the trip with the dynamometer car attached. A heavy passenger load was carried and the highest maximum and minimum speeds were attained of any of the trips. The number of stops per car mile was about the average, and the number of watt hours per car mile was high owing, probably, to the high speed maintained. The curves indicate that the motorman was fairly economical. This trip differed from the others as the trip was made between the car barns and Elmside.

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Trip 6a. (See Summary)

This trip was made with a lighter closed car on the Johnson Street branch and was made in the afternoon at a time of light traffic. The mean speed was not much different from the average of the mean speeds on the main line but the maximum speed was much less. The watt hours per car mile was also below the average of the readings on the main line.

Trip 6b. (See Summary)

The return trip had a higher mean E.H.P. than the outgoing, as might be expected, owing to the hard climb from the Ill. Central depot to the Capitol and the mean speed was also higher. Unfortunately the wattmeter reading for this trip was lost.

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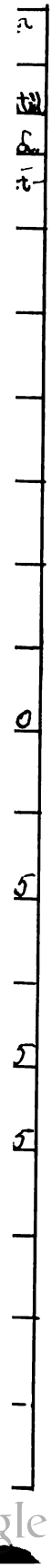

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Power on Curves.

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Location — Direction	Current Max	Current min	Current Ave	Volts Ave	E.H.P Ave	Grade per cent	Wgt Av.	Speed mi per hr	Length in ft.	Centrifl Incl. in feet
Williamson–Baldwin [South]	—	—	25	520	187		18,165	6.8		
Baldwin–Jenifer Sts. [South]			20	520	14	2.	"	7.		
Jenifer–Williamson [North]			24	528	17.2	1.3	"	—		
Wilson– " [East]			18	532	12.9		"	—		
Jenifer–Williamson [South]			21	528	14.8		"	7.8		
Wilson–King [West]	40	30	35	522	24.5	4.1	"	8.2		
Carroll–State "			26	500	17.5	3.2	"	—	67	80
" " [East]	39	35	37	484	24		"			
Main–Carroll (west)			22	520	15.4	.7	"	5.9	110	65
" " (East)			32.5	508	22.1		"		"	"
State–Park (west)			30	460	18.7	3.	"	—	86	45
Park–University "	44	21	32.5	506	22.		"	6.7	109	65
" " (East)			28.3	484	18.4		"	8.6		
Bresse Terrace–Monroe (west)	25	22	23.5	440	13.8		"	5.4		
" " " (East)			22	500			"	5.6		
Monroe–Cross-cut (West)						3.6	"			

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Power on Turn-outs

Location	Poles nos	Current max.	Current min.	Ave	EHP.	% Grade	Lbs Wgt	Speed
Jenifer St.	80-84	30	18	20	19	0	18460	5.9
Wilson "	106-107	35	22.5	27.1	19	1	"	6.6
King St.	121	39	30	34	2.32	3.8	"	6.8
State "	140	50	30	41.3	28.2		"	5.7
" "	172-3			43	2.78	.4	"	8.1
University Ave	200-199	31	17.5	24.8	16.7	.3	"	7.3
Baldwin St	62-4	25	22	19	16.1		"	6.7

Starting Currents.

	Grade %	Direction	Wgt. Lbs.	Amperes
King St.	4	Up	19540	110
University Ave.	4	"	"	120
Monroe St.	Curve		"	98
Park St.	.2	Down	18710	74
Williamson St.	Slight	Up	18380	45
Jenifer St.	Turnout		"	55
Wilson "	1	"	"	48
" "	3.8	"	"	52
King St (At Manor)	3.6	"	"	47
Bresse Terrace	2.5	Down	18140	62
Carroll St. (	3.2	Up	"	112
Williamson St.	Level (near)		"	76
" "	3	Down	18380	65
" "	3	Up	"	55
King St.	4	"	"	85
Wilson "	3.3	"	"	82

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Discussion of Curves. (See page 42 -)

What has been said in regard to the summary of the trips will apply in a general way to the curves. The relation between the current, volts and speed, for any portion of the road, is graphically shown for each of the trips. The road is broken up into many grades and the curves of current are very irregular. The curves, plotted on the grades, are very interesting and instructive. At the bottom of the grade there is, in each case, a violent rush of current. This is due to the force of acceleration, and as the car gets under headway the current falls, and, for a short stretch, approximates a constant value. At each of these grades, the curves of voltage show how the large amount of current causes the voltage to fall. The curves further demonstrate that the greatest starting currents occur at the foot of King and Carroll and at the corner of Sts., Bresse Terrace and University Avenue, where there is a sharp curve. The average curves of current follow, in a general way, the profile, the maximum occuring at about the middle of the grade. The curves of average speed are also higher at the grades than at other portions. The curves of average volts drop off directly as the distance increases from the power house, being the least at the two ends of the system. The curves of voltage are depressed at "up grades"

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and slightly raised at "down grades." Beyond Camp Randall, there is an abnormal depression due probably to bad bonding.

On trip 5(a), the dynamometer pull is plotted in addition to the electrical data. Between Baldwin St. and the station some of the readings, taken down hill, were due to the brake on the trailer. At most of the points along the road it is interesting to note the close correspondence between the curves of current and draw bar pull. For example, at the bottom of a grade, before the car has gotten under headway, there is an abnormal rush of current; the car accelerates, and the draw bar pull is consequently high.

Discussion of Power used on Grades.

On page 47, will be found a summary of the power used on the principal grades. In making this summary, a large number of current, speed and voltage readings were averaged from the tests. Efforts were made to select readings which represented the average conditions and which simply represented the power required to overcome friction and to lift the car. The highest recorded current of all the grades was that on the 5.5 per cent grade on Bresse Terrace. Next to this was the power used on King St. which is a 4 per cent grade. The speed on Breese Terrace was less than on any grade on the

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main line. On the Johnson St. branch, with the lighter closed car, the worst grade, as far as power consumption was concerned, appears to have been the 4 per cent grade on Hamilton St. W. Main St., which has the same grade, would be just as bad if the average speed maintained was as great as on Hamilton St.

The Baldwin St. grade is about the greatest of any grade in the whole system. On our test a low average speed was maintained and the electrical horse-power was some less on this grade than on some of the lesser grades.

On Johnson St., for about half a mile, is the only level stretch of any extent on either line. A high average speed was maintained here and the average E.H.P. was 11.35.

Discussion of Results on Curves and Turnouts.

On page 27c, will be found a summary of the results on the principal curves. The current values, with the radii of the curves, speed, and loads carried, make comprehensive data. On another page will be found a tabulation of the power required on some of the turnouts.

The chief characteristic of the power used on the curves is the uniformity of the readings. The maximum current was 37 amperes on the curve going from State to Carroll Sts.

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The minimum was on the curve going from Wilson to Williamson Sts. This value was 18 amperes. Most of the values, however, varied from 20 to 30 amperes.

Discussion of Traction Coefficient.

From the nature of the profile of the road, it is extremely difficult to have conditions of uniform speed and draw bar pull. The grades are numerous and short and the car is constantly changing its speed. An inspection of the curves of trip 5a, will show that the pull was at best irregular. However in a few instances there was nearly a constant pull, and computations of the traction coefficient, lift H.P. and traction H.P. have been made from the readings at such points and are tabulated in the table below.

Type of car	Location	Total load	Grade per cent	Pull in lbs.	E.H.P.	Traction coef. lbs. per ton	Traction H.P.	Lift H.P.	Speed
#23 open car	Jenifer St.	6000#	1.4	200	19.7	38#	2.78	2.05	9.1
"	Wilson St.	"	3.3	310	59.2	36#	3.59	6.2	11.8
"	King St.	"	4.0	330	64.5	30#	2.32	5.15	11.5
	Main	"	0.7	125	25.7	26#	2.51	1.39	12.4
	Brease Ter.	"	3.8	300	36.3	24#	1.61	5.1	8.4
Mean						31.2#			

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The average of our results seems to indicate that it required about 30 lbs. pull per ton to overcome the friction of the bearings and gearings, together with the friction of the car wheels upon the track. The track was fairly dry during the test, a slight rain having fallen the night previous. As the trailer had been stored in the barns all winter, the car was probably not in the best running condition, a fact which may have affected our results.

Comparisons.

In order to come to definite conclusions on the results, it is necessary to compare the tests with those made on other lines. A series of tests were made on the Madison St. car line in 1893 by Messrs. Smith, Glen Wray and Boardman. It will be of interest to compare some of their results with those of the present series. The company was running the lighter closed cars on both lines then and their results as to power on grades, etc. should be less.

They made no test of the resistance of the system but their insulation tests gave an average of 29,186 ohms for the total resistance. This, as compared to our measurement of 673.03 ohms, indicates that the insulation has probably greatly deteriorated since 1893. However, the fact that the road has been lengthened about two miles since then should be tak-

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en into consideration as this would decrease the total resistance.

The following is a table of their results on some of the principal grades. Our values are compared.

Year of test	Location of Grade	Per cent grade	Distance in ft.	Speed miles per hr.	E.H.P.
1893	Johnson St.	Level	2800	15.2	10.8
1898	" "	"	"	11.8	17
1893	King St.	4	700	9	22.1
1898	" "	"	"	11.3	43.3
1893	Carroll St.	3.2	660	7.3	25.9
1898	" "	"	"	10.2	39.2
1893	Main at C't House	5.3	800	8.8	25.5
1898	"	"	"	4.55	30.2
1893	Baldwin St.	6.3	270	7.9	35.4
1898	" "	"	"	4.55	36.7
1893	Hamilton St.	5.3	740	10.5	24.2
1898	" "	"	"	8.2	37.7
1893	Wilson St.	2.7	660	9.5	18.7
1898	" "	"	"	10	40.6

The loads were not considered in their tests but as our loads were light the two tests can be compared. From the

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results on the same grades the power required by the two types of car, when new, can be compared. For example, on King and Williamson Sts., the speeds in the two tests were about the same. On the King St. grade, the test of 1898 shows that the current required was 97 per cent greater than was required to run the cars in 1893. In the case of the Wilson St. grade, the increase was 111 per cent. This increase was due, in a small measure, to the increased weight of the cars and probably was largely due to the deterioration of the track.

In the case of the Johnson St. test we used the same type of car as was tested in 1893, but with the difference that our car had been in service for five years. The increase of power is not so great in this case, but is considerable, and is due largely to the track which has become very bad. Our results are compared with theirs, on curves.

Location of curve	Year of test	Av. speed	Av. E.H.P.
Main to Carroll	1893	6.8	11.2
Main to Carroll	1898		15.4
Carroll to Main	1893	5.8	13.9
Carroll to Main	1898	5.9	22.1
Williamson and Baldwin	1893	3.9	11.0
" " "	1898	6.8	18.7

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Again it is seen that the new cars take about twice the power of the old cars as they were running in 1893.

As to roads in other cities, the following comparisons are given.

Insulation.

Cincinati Inclined R'y.

Total insulation resistance, 25,000 ohms.

Resistance per mile, 300,000 ohms. Made after a heavy dew.

East Cleveland Railroad Company.

Cedar Street East.

Total resistance, 480,000 ohms.

Resistance per mile, 2,880,000 ohms.

Cedar Street West.'

Total resistance, 420,000 ohms.

Resistance per mile, 1,260,000 ohms.

Akron Railway.

Total resistance, 400,000 ohms.

Resistance per mile, 6,400,000 ohms.

Total resistance of Madison Railway, 673 ohms.

Resistance per mile, 5,842 ohms.

It is seen that the insulation resistance of Madison is extremely low.

Below will be found some values obtained on grades of

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the Pikesville road of the Baltimore Traction Company.

The total weight carried was about the same on these tests as on the Madison tests. The motors were two 25 H.P. Westinghouse motors.

Test	Grade	Speed mi. per hr.	Total Wt.	E.H.P. at car
Baltimore	5.96	4.15	17,135#	21.6
"	"	10.41	16,935#	43.2
Madison	5.5	8.4	18,850#	45.7
Baltimore	2.6	5.66	17,185#	12.5
"	"	12.37	17,235#	29.3
Madison	2.3	12.8	18,540#	27.5
Baltimore	5.96	8.37	23,573#	55.0
Madison	5.5	8.4	18,850#	45.7

The results on the two roads agree very well, especially when comparisons are made where the speeds and the grades are the same. The best comparison is made on the basis of the watt hours per ton mile.

The following table gives some values of the watt-hours per ton mile on several roads.

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Road	Total Load tons	Watt-hours per ton mile
N.Y.N.H. & H. R.R.	34 (1)	81.7
" "	64 (2)	60
Edmondson Ave.Line Baltimore	8 (3)	138
Carey St.Line Balt.	8 (4)	134
Linden Ave. Line "	8 (5)	160
Roland Park & Lakeside "	8 (6)	138 (Express run)
Balt. & Pikesville	8.6	90 (Express run)
Roland Park & City Hall	8.1	142 " "
Madison	9.25	171

(Readings of round trips compared.)

The Madison test has a higher value than any of the tests. The first two cases given are hardly comparative cases as the road is suburban and the rolling stock is much heavier than ordinary practice. The value of 60 watt-hours per ton mile is, no doubt, near the minimum limit. The third, fourth, and fifth cases are from tests made under very similar conditions to the Madison tests. The loads carried were nearly the same and the cars were equipped with 2 - 25 H.P. Westinghouse motors. The Baltimore tests were made in 1894 by

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Hermann S. Herring and the N.Y.N.H. and Hartford R.R. test was made by Mr. Heft, in 1897. In this connection, it is interesting to note the power required at the station per car. The following table gives some of the results obtained from tests at the Madison power station, in recent years. At the same time the results are compared with those obtained from power stations of other similar cities.

Place	No. Cars in operation	Max. I.H.P	Aver. I.H.P.	Max. E.H.P.	Aver. E.H.P.	Aver. Amp.	Aver. I.H.P. per car	Aver E.H.P. per car
Madison, Wis.	8	248	117.5	130	92.76	140	14.69	11.59
Utica, N.Y.	20		190.5		154.3		9.52	7.72
Wyandotte & Detroit River	3	141	70	90.27	45.	67	25.25	15.54
Syracuse, N.Y.	7		51.4		33.5	50	7.80	7.4
Cortland, N.Y.	6		60.4		48		10.66	8
Auburn, N.Y.	6		80		63.04		13.33	10.5
			Averages				13.3	10.19

It is seen that these tests also show that the power required per car on the Madison Road is a little above the average. —The data of many car tests indicates that the stops per car mile on busy roads average about 8; 1.4 for suburban roads, and 3.4 for city and suburban roads. The average of

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the stops per car mile, upon our tests, which was 2.55, falls between the average values for busy city traffic and for city and suburban traffic.

In a series of careful tests made by Mr. Hering in 1893, on roads in the vicinity of Baltimore, he found that the traction coefficient for a trailer, similar to the one we used, was 8.6 lbs. per ton. (See St. Railway Gazette, 1895). His experiments were made over finely equipped roads similar to steam railroads.

For average street railway practice, the coefficient is given by authorities as varying from 20 to 30 lbs. per ton. It would seem, then, that the value of the coefficient from our test was high.

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Conclusion.

The company's road is badly maintained while the cars and motors give fair service. The insulation is bad and the resistance of the ground is altogether too high. Our tests indicated that the ground had a greater resistance than the overhead circuit, while good practice dictates that the reverse should be the case. The most striking conclusion, as brought out by the tests, is the varying efficiency of the motormen. The company should require that their motormen be more economical of the power and should be strict in enforcing this requirement. The return circuit should be made better and the points that cause bad insulation resistance should be sought out and cared for.

References (Hering, St.Ry.Gazette, August, 1895.)

" (Heft - St.Ry. Journal, June, 1897.)

The author wishes to acknowledge the kindness of Mr. Shaw, Superintendent of the Road. He gave every assistance and made many determinations possible that otherwise could not have been determined.

Thanks are also due to Messrs. Lippert, Kellar, Olsen, Hurd, Nee, King, and Schroeder, who gave valuable assistance in taking readings.

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Explanation of Curves

Full lines from Elmside to Cemetery

Dotted " " Cemetery to Elmside

Grade line

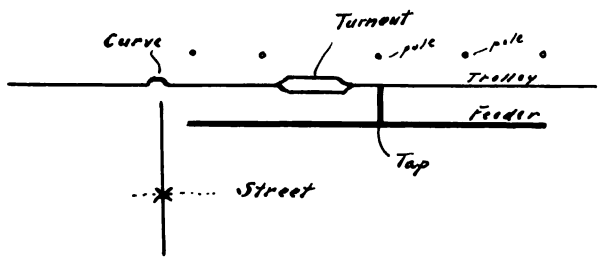
Volts

Speed

Amperes

E. Horse Power

Draw Bar Pull



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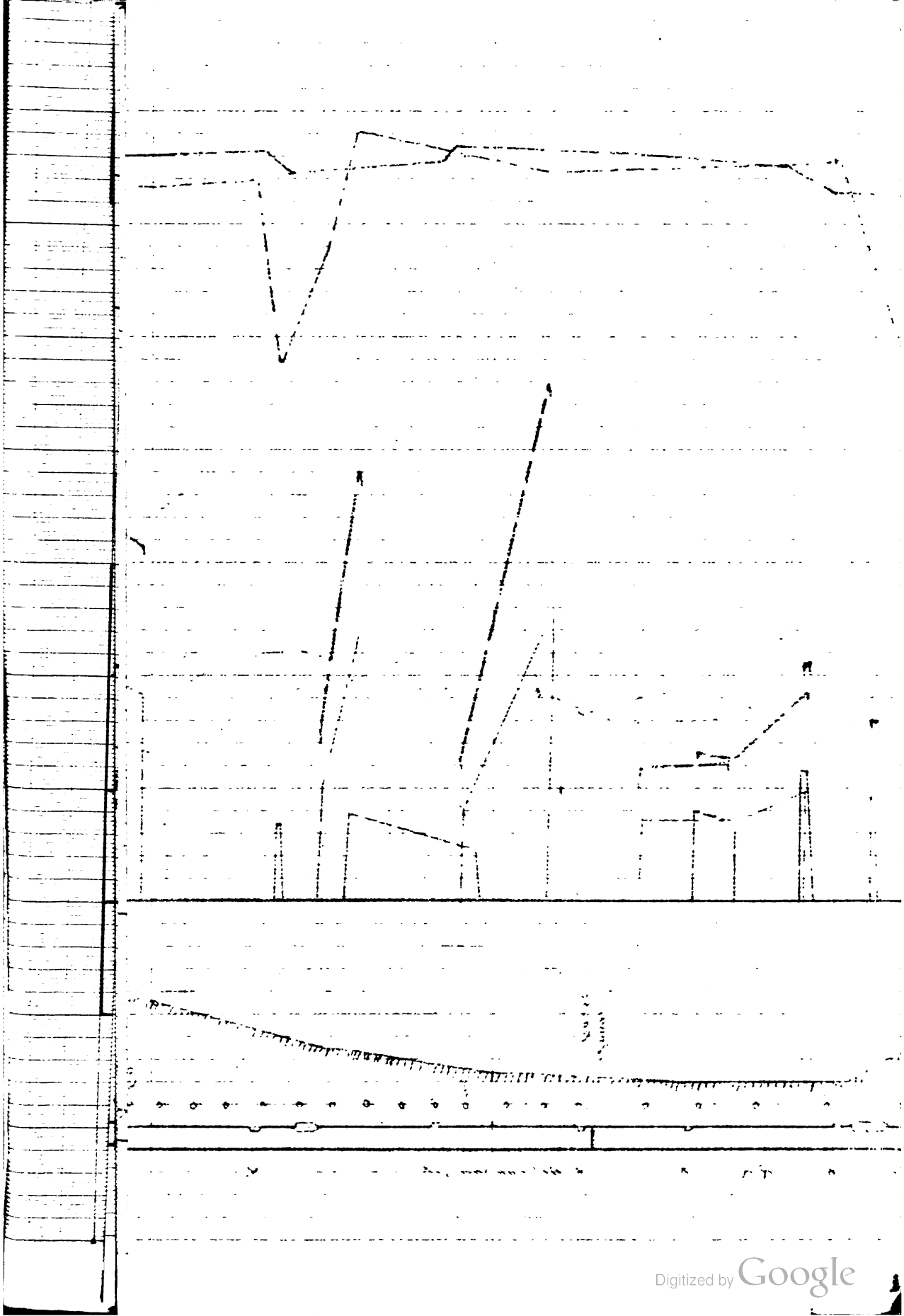

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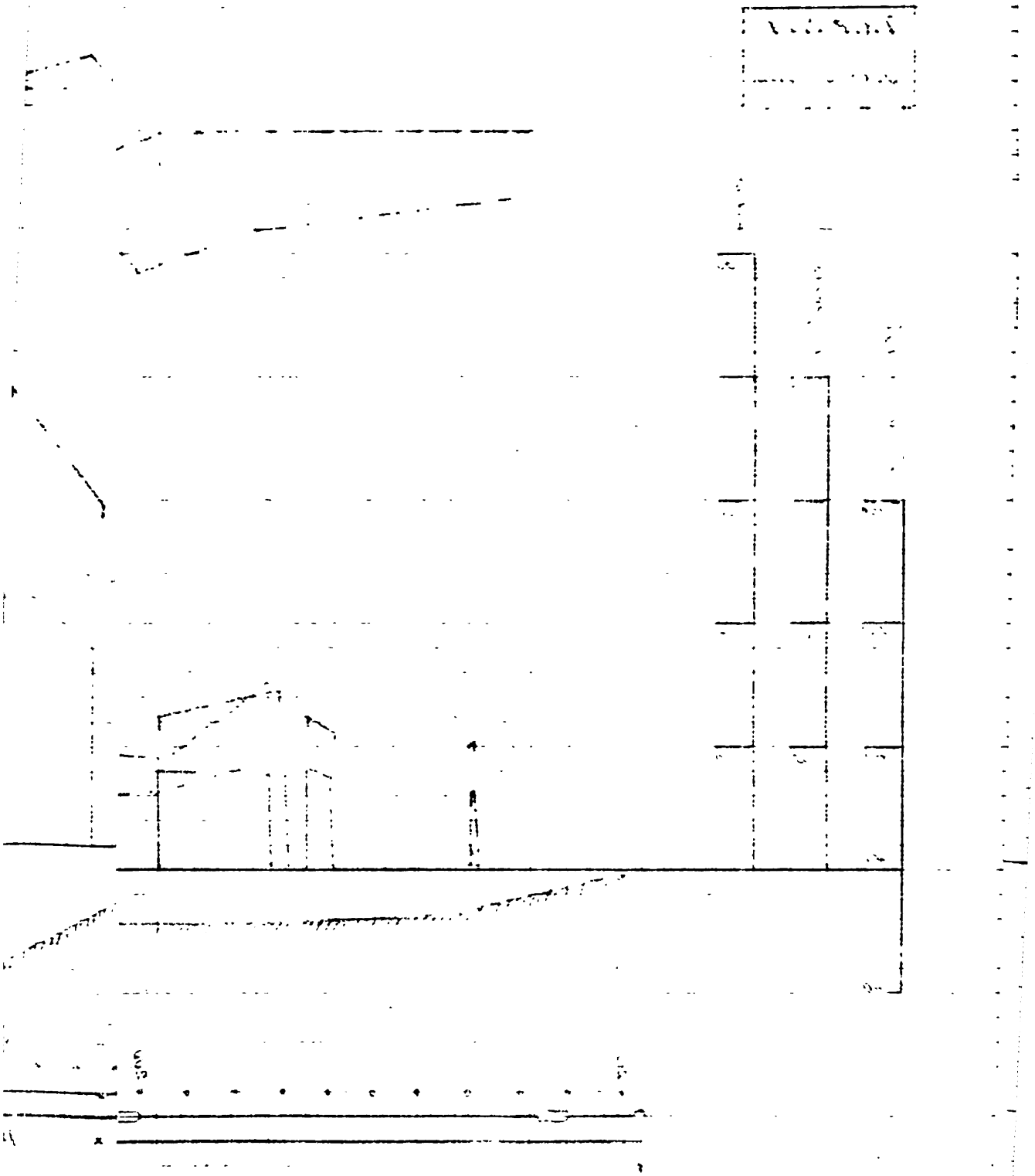

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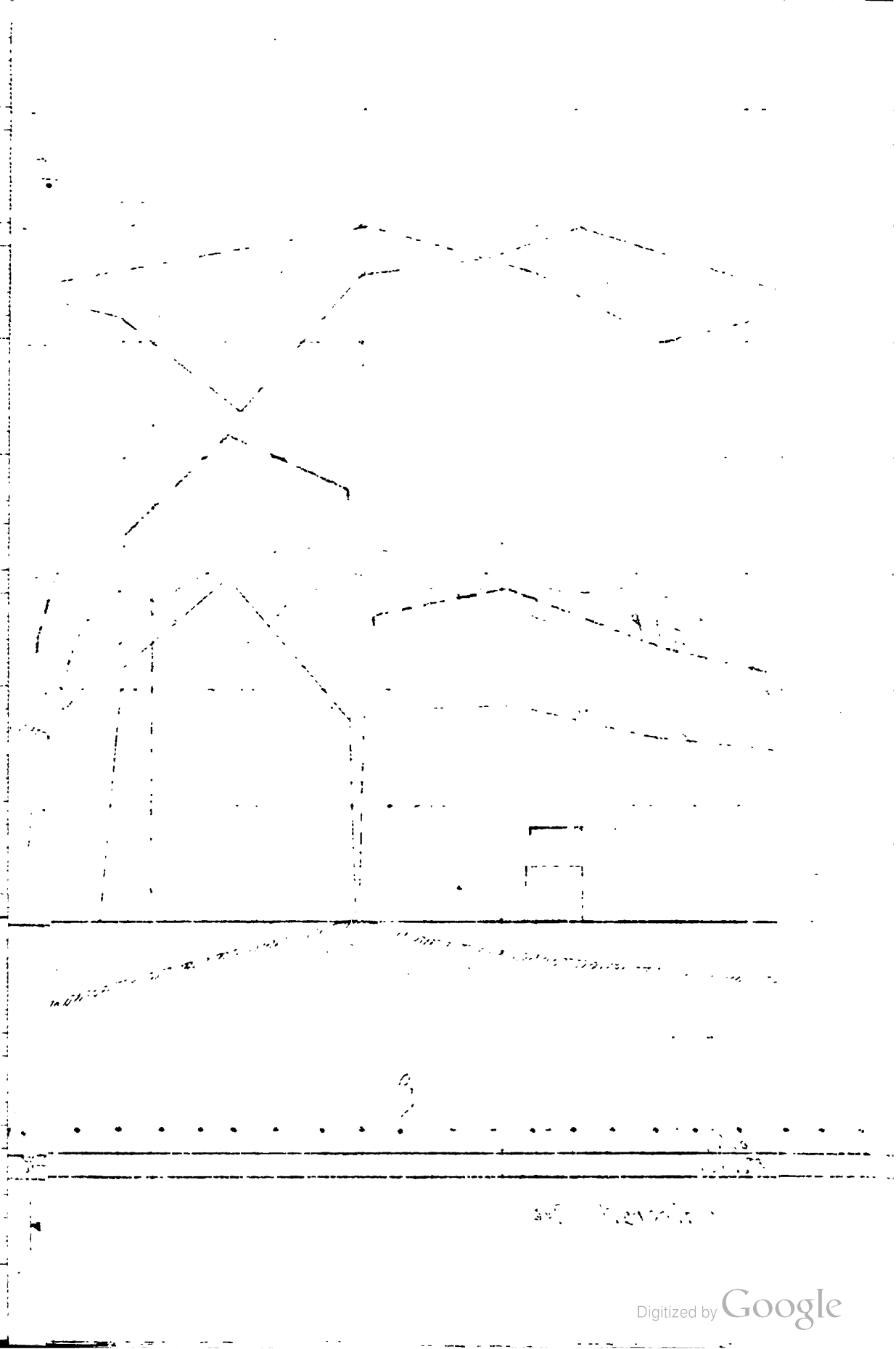

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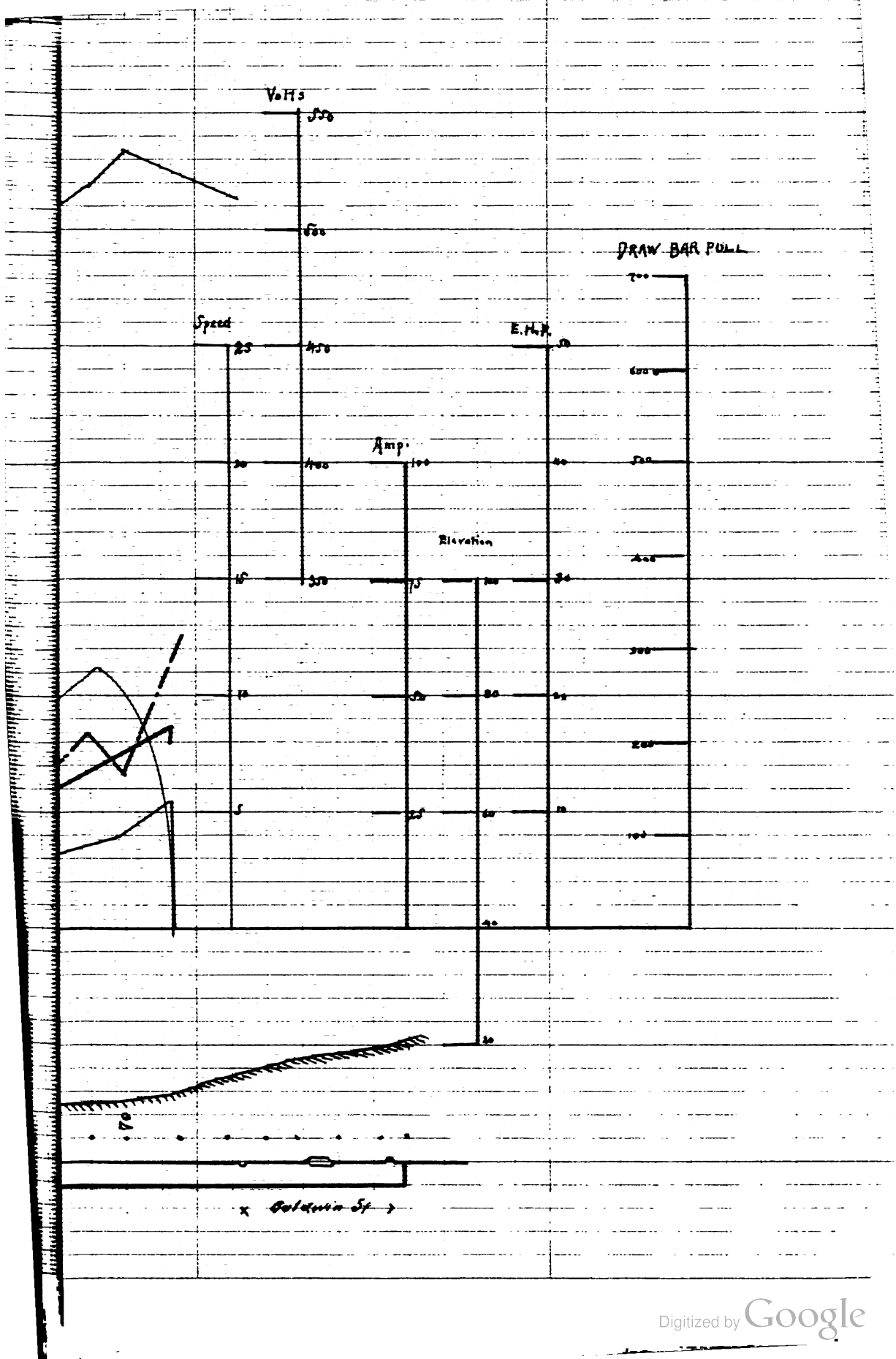

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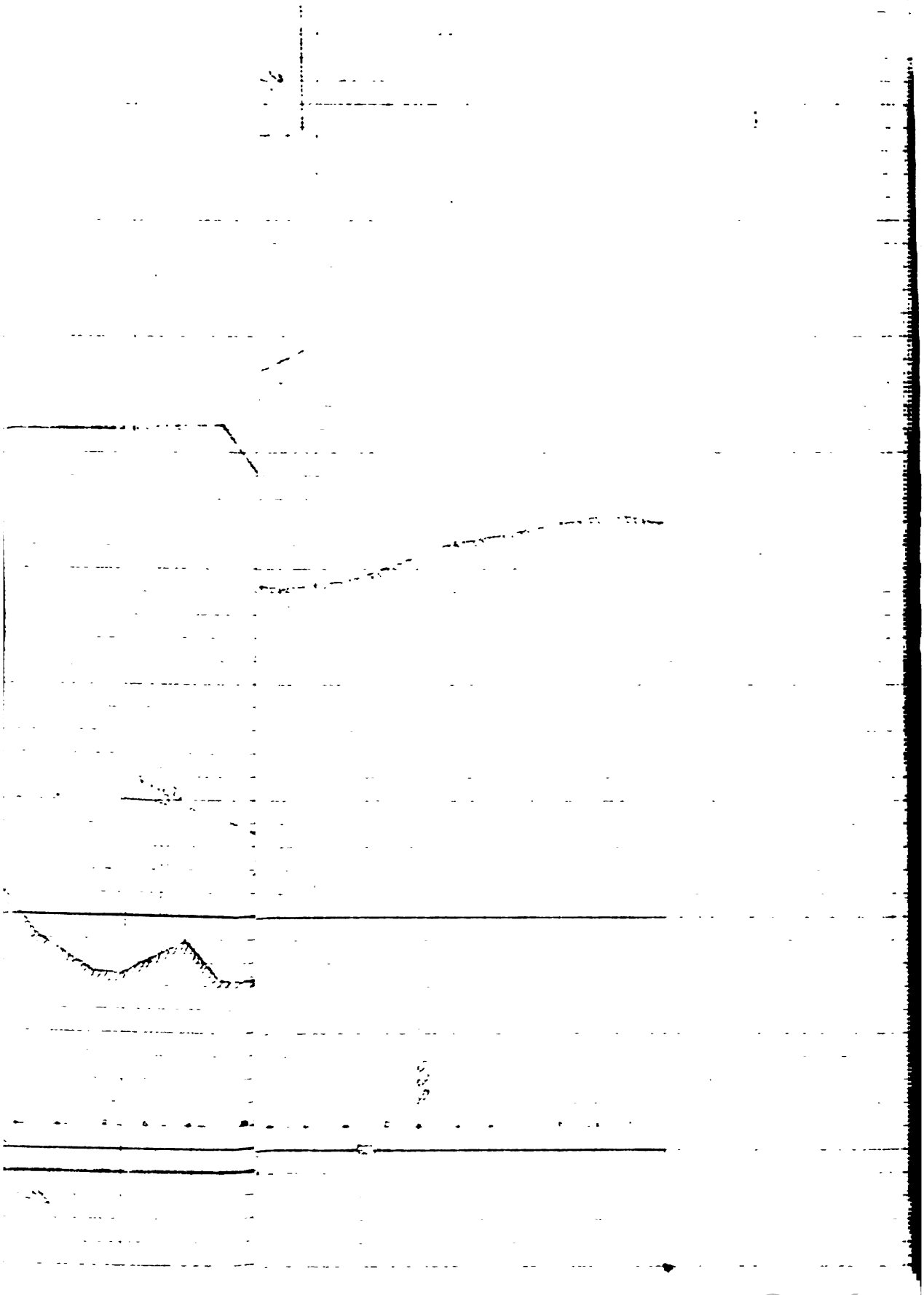

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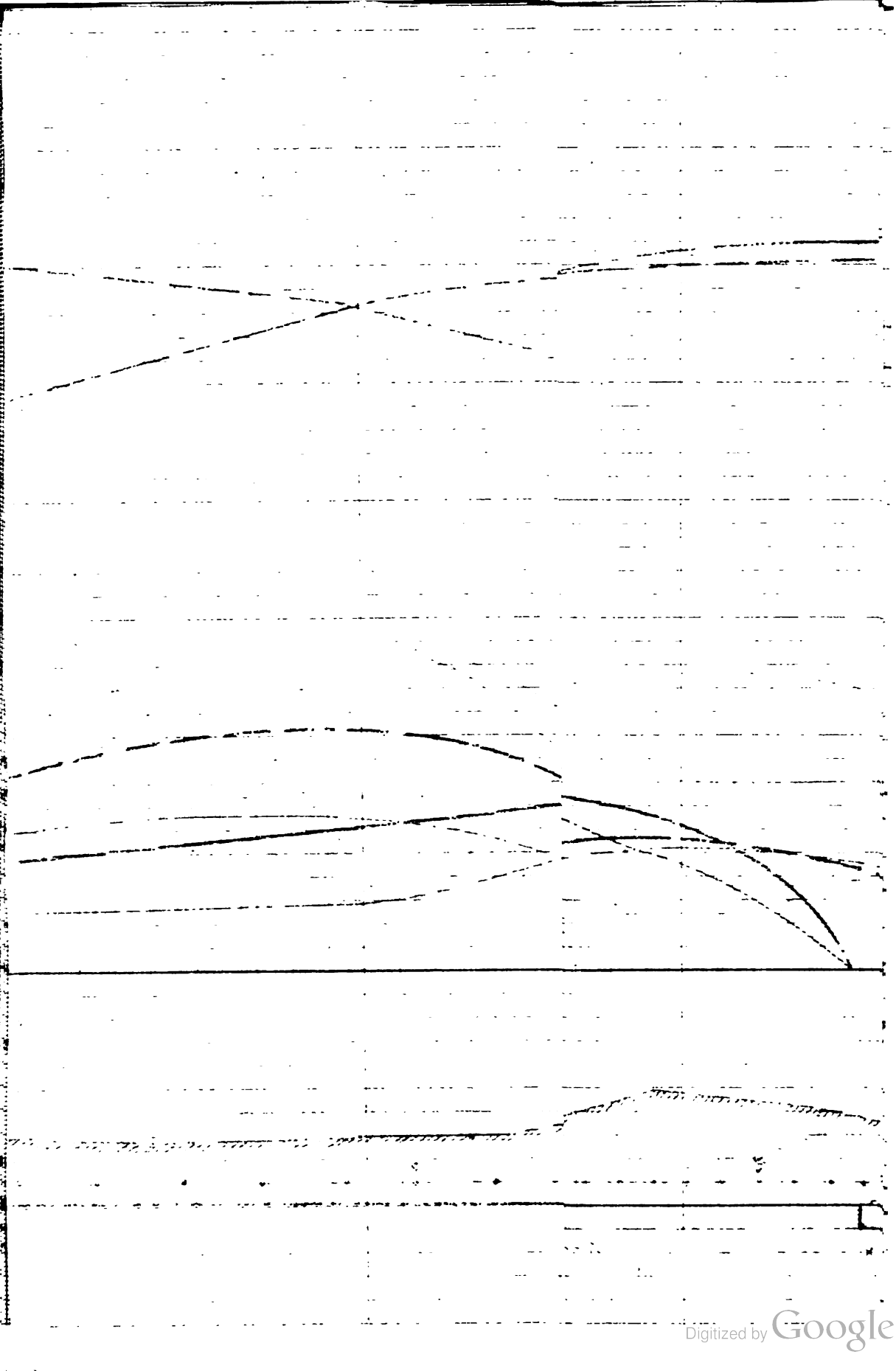

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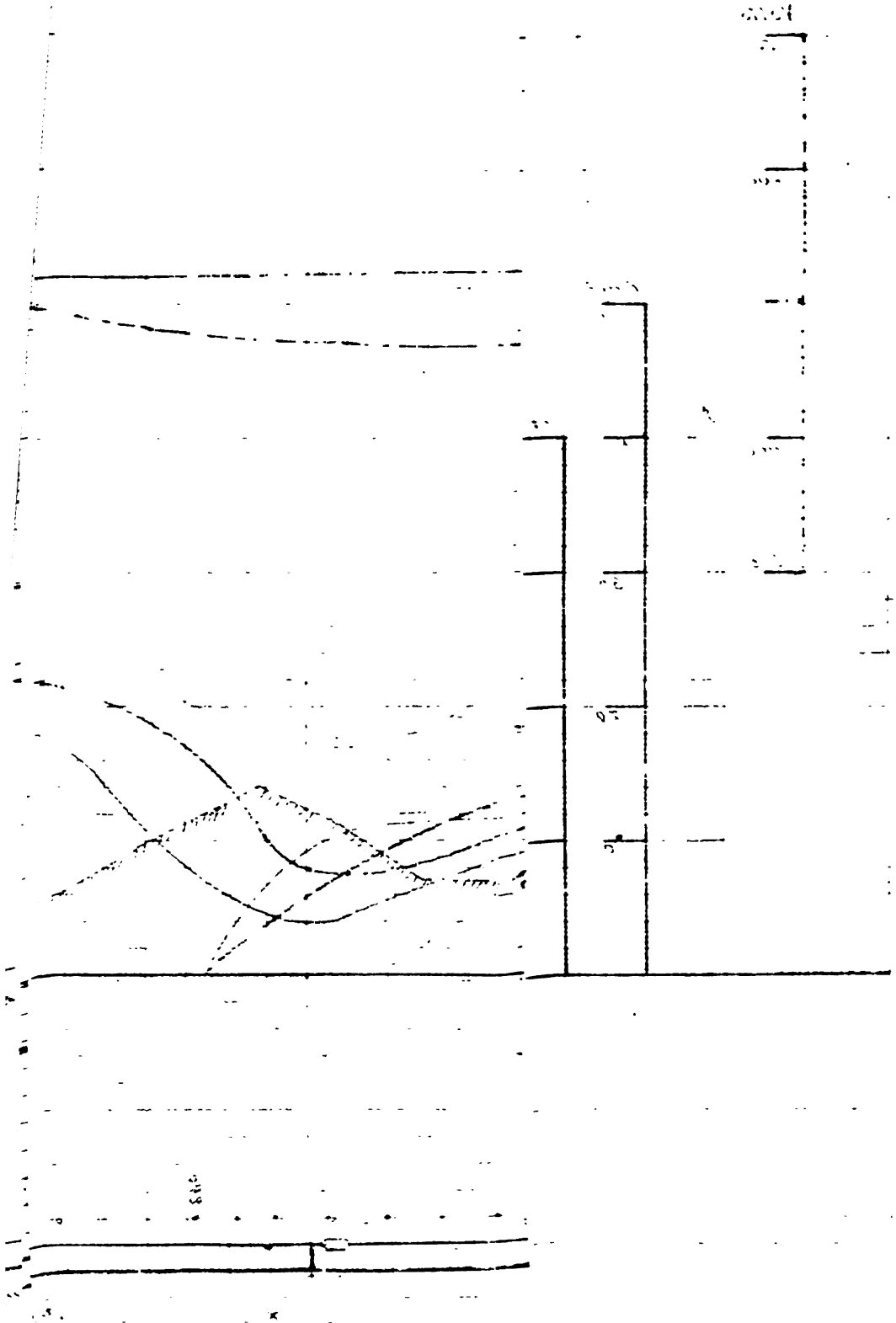

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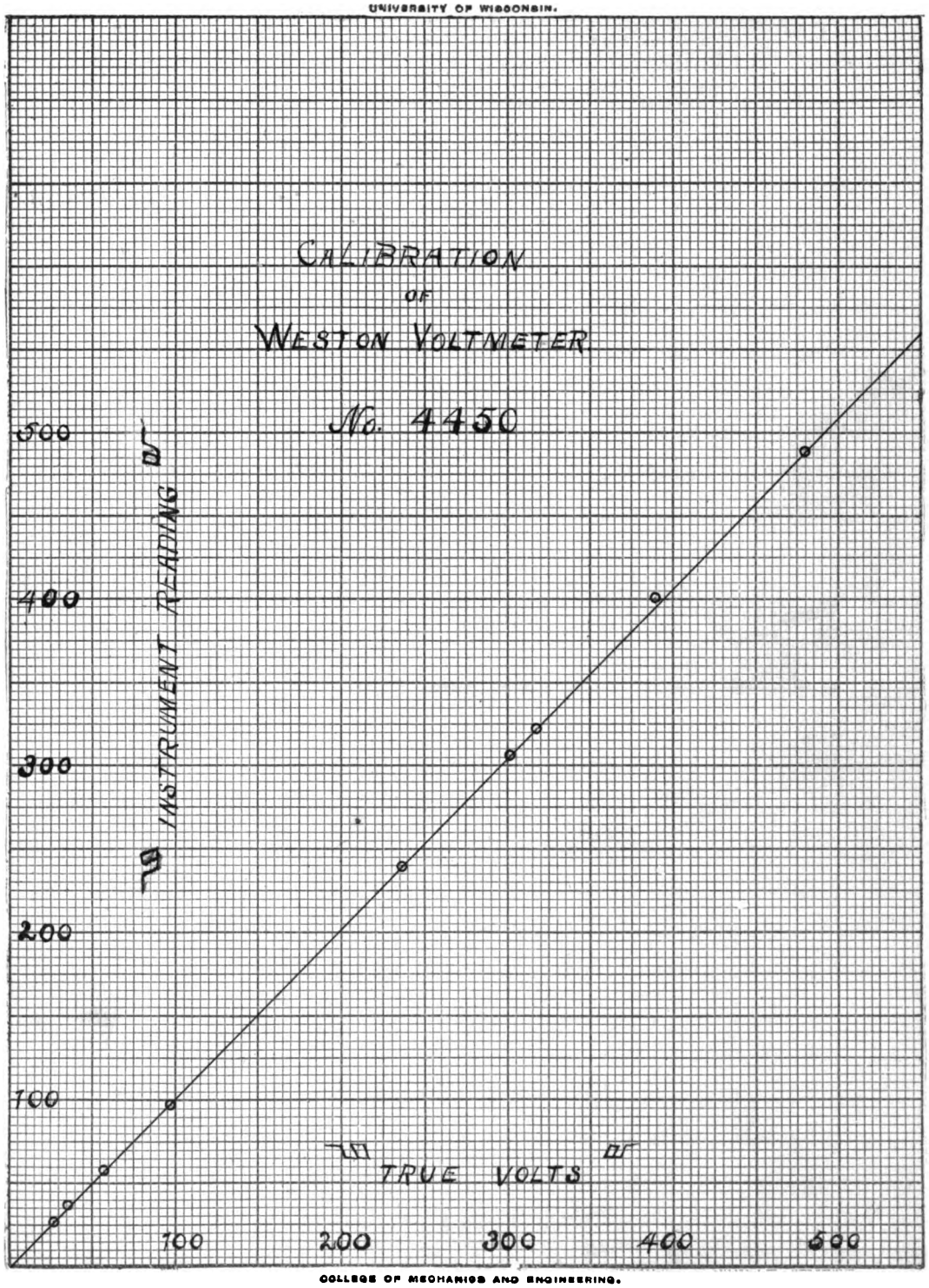

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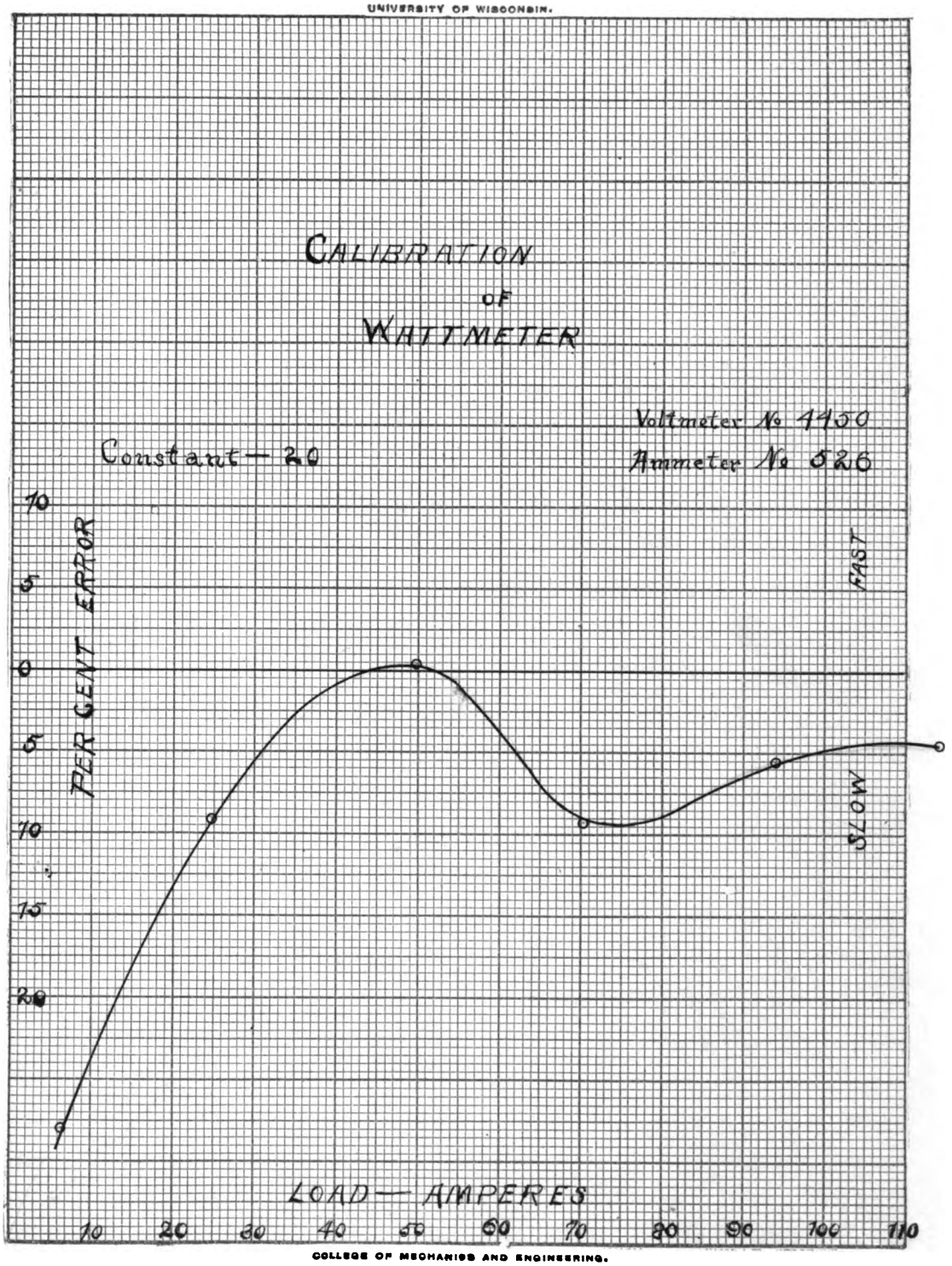

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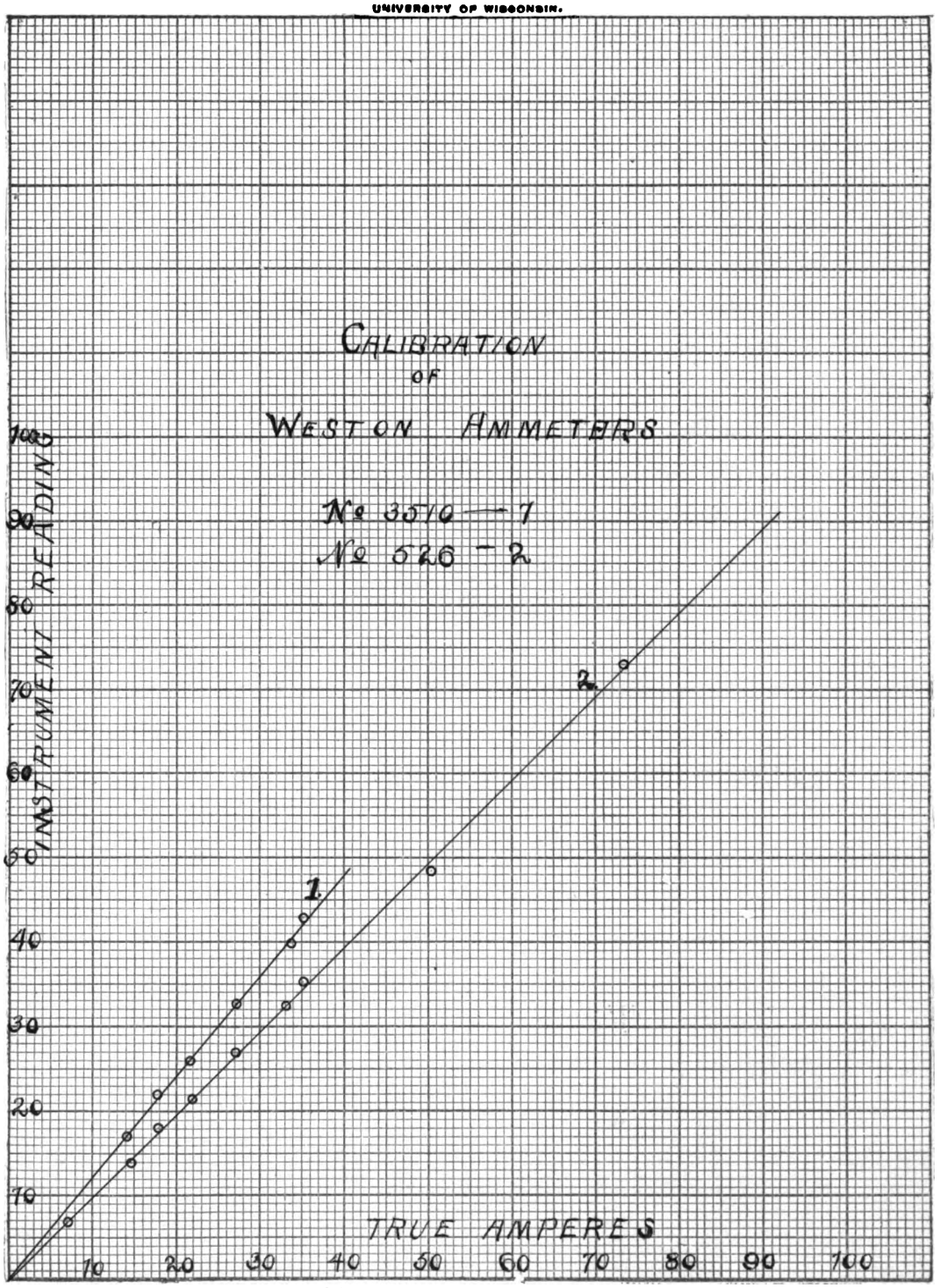

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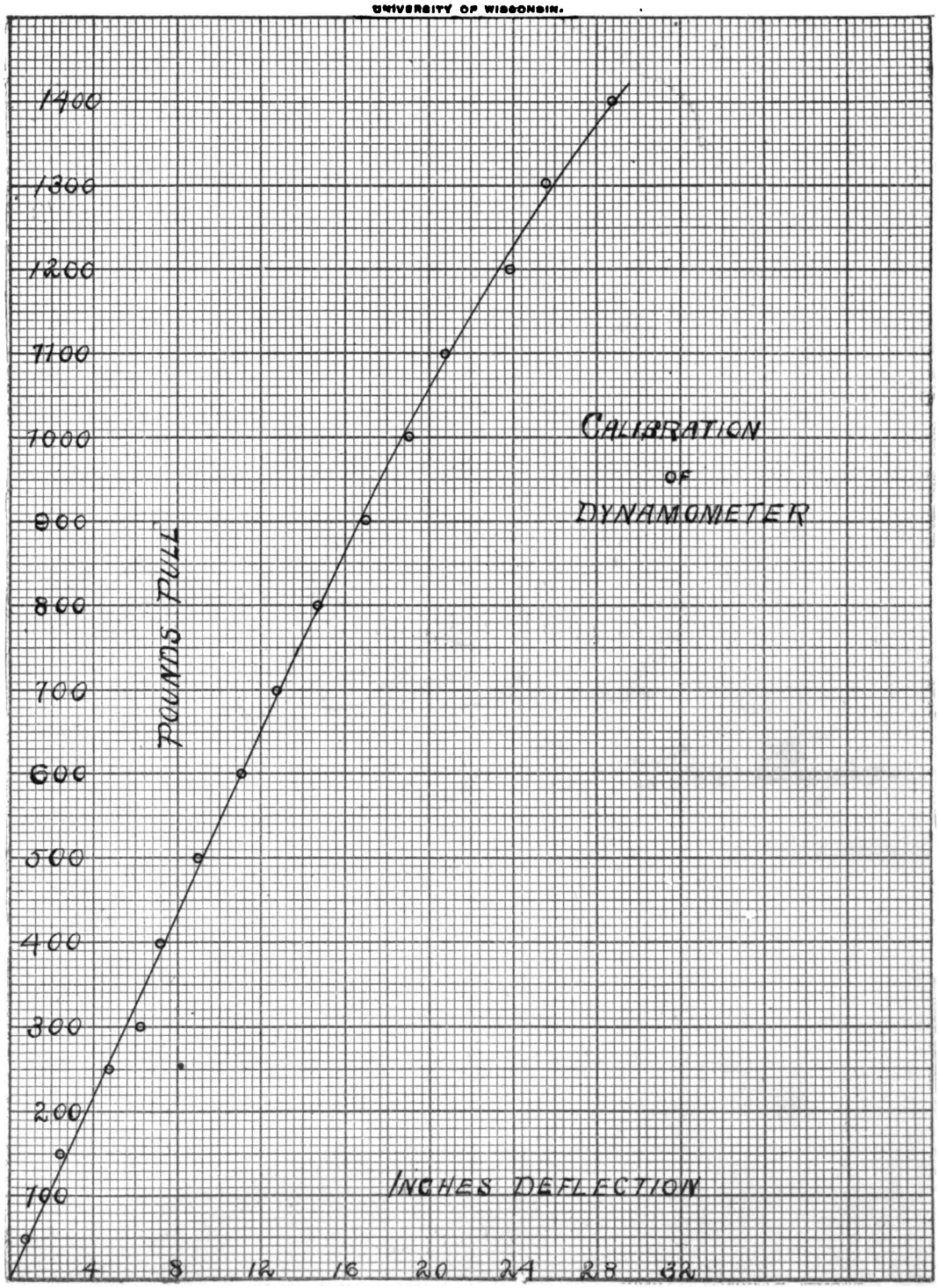

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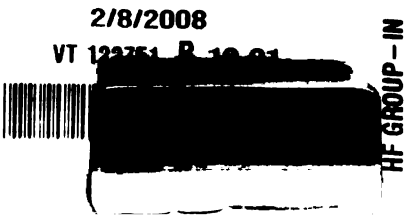
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